(12)

TECHNICAL REPORT CSMI/TR-83/02

Final Technical Report:

The Design, Development, Demonstration and Transfer of Advanced, Computer-Based, Command and Control (C2), and Video Teleconferencing Systems

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December 1983

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER CSMI/TR-83/02	2. GOVT ACCESSION NO. AD-A137 649	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) The Design, Development, Demonstration and Transfer of Advanced, Computer-Based, Command and Control (C^2) and Video Teleconferencing Systems		5. TYPE OF REPORT & PERIOD COVERED FINAL REPORT Oct 1, 1979-Nov 30, 1983
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Kevin F. Vest, Keith A. Olson, Patrick L. Jones, Shireen Yacuoby, Douglas H. French, James F. Wittmeyer		8. CONTRACT OR GRANT NUMBER(s) MDA903-80-C-0155,
9. PERFORMING ORGANIZATION NAME AND ADDRESS Computer Systems Management, Inc. 1300 Wilson Boulevard, Suite 100 Arlington, Virginia 22209		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS ARPA Order 3829
11. CONTROLLING OFFICE NAME AND ADDRESS DARPA/DSO/SSD 1400 Wilson Boulevard Arlington, Virginia 22209		12. REPORT DATE December 10, 1983
		13. NUMBER OF PAGES 40
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) Defense Supply Service-Washington The Pentagon Room 1D245 Washington, DC 20310		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

UNLIMITED

DISTRIBUTION STATEMENT A
Approved for public release; Distribution Unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

UNLIMITED

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Demonstration and Development Facility (DDF); micro-computer systems, command and control; forecasting; training; engineering; evaluation; real-time; real motion; videodisc; Telepad; video teleconferencing; virtual space; shared data; Shared Graphic Workspace System (SGWS); Videolab; low-bandwidth network.

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Department of Defense information processing and command and control require research, experimentation, evaluation, synthesis, documentation, demonstration, production and transfer. The Demonstration and Development Facility (DDF) was the first stage in the fulfillment of this requirement and a low-bandwidth video teleconferencing network is the most recent development designed to meet these myriad requirements. Both the first and most recent stages were designed to meet the needs of the commander for understanding information and communicating decisions.

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SUMMARY

This Final Report covers the period from October 1, 1979 to November 30, 1983. The tasks, objectives and/or purpose of the project are concerned with the design, development, demonstration and transfer of advanced computer-based command and control (C2) systems. This report summarizes work from the entire contract period, beginning with the computer/support center known as the Demonstration and Development Facility (DDF) and ending with the work in the area of video-teleconferencing and graphics. Emphasis throughout the contract was placed on the development and experimentation of these diverse systems. This report stresses those guidelines, and examines the progression of the project from its formative beginning to its sophisticated completion. The single driving idea behind the entire project was to develop means that would enhance command and control capabilities. Although almost entirely experimental, the final product of this project is a clear manifestation of that idea.

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FINAL REPORT

1.0 INTRODUCTION

This Final Report covers a single project beginning with two years of computer operations and support and ending with two years of advanced micro-processor and video-based research and development. Because many technical writings, demonstrations, video reproductions and complex computing and engineering efforts have been produced during the four years, little effort will be made in this report to give a detailed accounting of the technical work. Indeed, it is best not to attempt such an undertaking, for the best way to review this effort is to see and use the final product---a multi-node video-teleconferencing network. Because the reader is urged to experience the technology, the main emphasis of this report will be on the general evolution of this project. This evolution was given direction by the Cybernetics Technology Office (CTO) of the Defense Advanced Research Projects Agency (DARPA). Content of the evolution was given by Computer Systems Management, Inc. (CSM), the contracting company.

In the first two years of the contract period with the DARPA office (under several different names) an effort was made to integrate various DARPA supported research projects. During the last two years, unique applied research in the micro-processor field was initiated. CSM was the point of integration and then the leader in the research effort. The significance of these two seemingly separate assignments is that CSM was tasked with

supporting, integrating and demonstrating many projects designed for Defense Department applications and transfers. This gave to CSM the unique and valuable opportunity to synthesize not only current computing applications but also to evaluate the technologies that the Defense Department would need for its future command, control and communications requirements. Precise requirements (such as cost, power and size of micro-processors) established the guidelines for the specific research and development efforts undertaken in the final two years of this project. Because CSM initially enjoyed the role of integrator and synthesizer, and possessed the skills necessary for this role, it was a logical extension to put into place the ideas and experience it had accumulated during the first two years of this project.

With these several thoughts in mind a few organizational remarks are necessary. Following this section is a section on the first two years of the project. Next is a transition section and following that is the heart of the report, the section dealing with advanced technological research and products. A final section concludes this report.

Finally, it must be reiterated that this report cannot fairly represent all the work, all the thinking, and all the engineering and computing effort that occurred during the span of this project. All those factors can be understood and appreciated only by hands-on experience or personal demonstration. This report, therefore, seeks only to be either an introduction, for those who have not encountered the technology, or a conclusion, for those who have, to a fascinating component of the rapidly evolving

information industry.

2.0 DEMONSTRATION AND DEVELOPMENT FACILITY (DDF)

All activity in the first two years of the project centered around the Demonstration and Development Facility (DDF). The DDF was primarily a computing facility for DARPA sponsored research projects. The DDF was operating three (3) DEC PDP 11/70s on a 24 hour basis.

2.1 GENERAL TASKS

Making sure the computers kept working was only one aspect of the mission. In addition, for all users of the DDF, CSM had responsibility for quality control of software design and hardware selection, for consulting on data base specifications and characteristics, and for maintaining additional information such as internal (in the software) and external (user manuals and code books) documentation.

Other general responsibilities included demonstrations of the various projects located at the DDF. Briefing these products to potential Defense Department users and helping transfer these products, if the briefings were successful, were also DDF responsibilities.

It was apparent that the Demonstration and Development facility was more that a computing facility. Beginning in the first year of the project CSM became involved in the design phase of all

DARPA/CTD products by being responsible for integrating hardware and software capabilities. And the DDF was assigned the leadership role of organizing and presenting demonstrations. This experience is particularly important because these demonstrations are the precursor to more technically advanced forms of briefings and conferences.

2.2 MICRO-COMPUTER SYSTEMS

At about the same time the DDF was initiated, DARPA/CTD began its Command and Control Decision and Forecasting Program. Its primary mission was the design, development and application of advanced computer-based systems for enhanced command and control processes, especially as they involve the "commander" as a decision-maker and forecaster. With little elaboration, this program combined research and development tasks with Defense Department related activities, such as crisis management, and with the operation of the computing equipment by the "commander" or a small group of people. This meant that all aspects of computing operations (both hardware and software) had to be "user friendly" and, in general, able to run on micro-systems.

CSM was tasked with evaluating existing command and control computer-based systems and made recommendations for improving the design and construction (within DARPA parameters) of these systems. A variety of these systems existed and it was CSM's task to extract the commonalities and/or distinguishing characteristics of each. To those unfamiliar with DARPA-supported research, the following list may be nothing but a jumble of acronyms.

Nevertheless, even the unfamiliar can appreciate what appears to be, and in fact is, a wide variety of computer-based systems.

- The Early Warning and Monitoring System (EWAMS);
- The Executive Decision Aids;
- OPINT;
- EVAL;
- INFER;
- RAM;
- DECISION;
- The (Counter-) Terrorism Research and Analysis Program (TRAP);
- The Adaptive Information Selector (AIS);
- The Spatial Data (Base) Management Systems (SDMS);
- The Ultra-Rapid Reader (URR);
- The Marine Corps Combat Readiness Evaluation System (MCCRES), among others; and
- PRESS

Evaluation of these systems resulted in an exhaustive list of criteria and/or capabilities to be carefully reviewed before construction of computer-based systems began. The following list is designed to illustrate the breadth of information industry knowledge necessary to make prudent decisions. Special attention should be allocated to Input Devices and Display Devices (under Hardware) and Display Properties and Display Coding Techniques (under Software). These factors illuminate the variety of characteristics that must be considered prior to developing a forecasting or decision-aiding computer system. The criteria include:

- Requirements Analysis
  - Organizational/Bureaucratic;
  - Substantive;
- Hardware
  - Mainframe;
    - Minicomputer;
    - Microcomputer;
  - Storage Devices,
    - Hard;
    - Soft (Expandable);
  - Input Devices;
    - Keyboards;
    - Lightpen (gun);
    - Joystick;
    - Trackball;
    - Mouse;
    - Graphical Input Tablet;
    - Touch Panel;
    - Knee Control;
    - Speech;
  - Display Devices;
    - Refreshed CRT;
    - Storage Tube CRT;
    - Plasma Panel Display;
    - Teletypewriter;
    - Line Printer;
    - Laser Display;
    - Large-Screen Display; and
    - Graphical Display;

- Portability;
- Reliability;
- Appearance;
- Processing Speed;

- Software
  - Language;
  - Structure;
  - DBMS;
  - Statistical Packages/Routines;
  - Display Properties (Alphanumeric Characters);
    - Font;
    - Size;
    - Case;
    - Spacing;
    - Aspect Ratio;
    - Cursor;
  - Display Coding Techniques;
    - Shape Coding;
    - Color Coding;
    - Blink Coding;
    - Motion;
    - Depth;
    - Line Type;
    - Focus or Distortion;
- Interaction Mode/Dialogue Types
  - Q&A;
  - Form-filling;
  - Menu-selection;
  - Function Keys with Command Language;

- User-initiated Command Language;
- Query Language;
- Natural Language; and
- Interactive Graphics.

2.3 ENGINEERING SUPPORT

While the above gives the details of the DDF activity, CSM concentrated its support in the general activites of: operation of the time-sharing service; providing user-community programming and software support; expanding the facility library to track the needs of the users and DARPA/CTD; providing engineering support to all areas inside and outside the DDF; and providing new product support.

Of particular interest is that CSM became involved in providing engineering support for the DDF. Engineering activity added a new dimension of additional experience to what was previously a computing and conferencing (through demonstrations) facility. The need for engineering support of this type was clear, however, because of the size and complexity of the CSM/DDF operation, and because all the work was Defense related and on government furnished equipment, it was necessary to become less reliant upon the service of non-CSM/DDF personnel. It was felt that the best way to provide complete services and support at such a unique facility was to make the facility a self-contained unit. One of the first tasks completed in the engineering area was the construction of a new and environmentally sound computer-room. Other than the initial computer-room contruction, CSM conducted

the following activities under engineering support:

- electronic equipment repair;
- facility layouts, and design in the areas of drawings, construction, mechanical and electrical plans;
- terminal repairs and renovations that require few spare parts inventories;
- power consumption level monitoring and conservation;
- special wiring, cabling, and inter-device/system connections;
- special small projects design, (e.g., microcomputer interfaces or remote control switchers for audio and video in demo room); and
- communications equipment support and performance of quarterly status evaluations.

2.4 OTHER TASKS

Another task of CSM/DDF during the early period of the project was to monitor new developments in the information industry. One of the most exciting at the time was the videodisc. The videodisc provides a tremendous amount of information storage and provides it very economically. In addition to its storage capacity, the chief advantage of the videodisc storage system is that it permits the storage of sound and of video photographic images of all kinds.

Despite the rather severe disadvantages of videodisc technology (such as the high cost of manufacturing and the inability to update information on the disc), the potential for using these storage devices was far reaching. Any information that was static in nature could be stored cheaply and well and any video

production that was used over and over (such as a demonstration or training film) was a natural for videodisc technology.

Videodisc technology was attracting attention because analysts, decision makers and others were realizing the importance of using video images, as opposed to text or numbers, for presenting information. Indeed, CSM/DDF and DARPA were often requested to give demonstrations for out-of-town visitors, who often went to great expense to get to the demonstration. A video technology that could capture the demonstration and send the image to the viewer would save both time and money. Similarly, the possibility of doing a demonstration once and then showing repeatedly the demonstration had great appeal.

CSM/DDF was asked also to investigate the developments made in the linking, or networking, of various kinds of information and analytical systems. At the time of the initial investigation only a few networking modes existed. These included local networks, where individuals accessed shared information as individuals from geographically close and similar stations, local networks where groups jointly access information and solve problems, remote individual networks and remote group networks. Remote group networking is also known as teleconferencing and it may or may not be video supported.

2.5 SUMMARY

The Demonstration and Development Facility started as a computing center and after two years of Computer Systems Management direc-

tion it emerged as the primary location, not only for computing, but also for systems integration, quality control and evaluation, engineering, and as the research center for unearthing and evaluating new and often little known technologies. It is clear that the CSM/DDF was poised for becoming a creator of new products. Also, CSM was undergoing the transition that many information companies were going through; namely, moving from being a service provider to a systems integrator. But this was a Defense Department (DoD) project, and DoD was undergoing changes also, particularly how it (DoD) viewed its place in the information industry.

3.0 CHANGING PRIORITIES

The DDF was established to give computing support to a variety of national security-oriented analytical problems. This fact alone made the DDF enterprise fairly unusual enterprise. But to appreciate the direction taken after the DDF era requires some background and a view of how priorities were changing in one office of the Defense Department.

In the early 1970s very few computer-based solutions to decision, forecasting, training, and information management problems were available. Initially the solutions were geared to information overload and "accounting" problems; decision-making, forecasting, and training problems, as well as those dealing primarily with analytical rather than procedural matters, were relatively neglected. The emphasis was on information collection, processing, storage and retrieval. In fact, the very first production

systems occurred in two totally unrelated areas: budgeting and large scale data processing connected with weapons development. Only later did the role of the individual forecaster, decision-maker, planner, evaluator, trainer and information manager---in the analytical context---become the focus of serious research and development.

It is also important to note that the legacy of 1960s computing was comprised of large, "macro" systems supported by relatively inflexible software. Consequently, there was in the early 1970s, a fundamental incompatibility between the available hardware/software and the demands and requirements at individual cognitive operations.

In the mid-1970s, however, "decision support systems", "user-oriented" data base management systems, and a potpourri of analytical algorithms were developed, tested, and applied to many cognitive operations and tasks. Minicomputers and (clumsy) microcomputers also proliferated the computing environment during the mid-1970s.

In the late 1970s enormous changes occurred in the applications sphere. More and more Defense Department agencies and offices, through impressive research and development efforts, began to augment their problem-solving procedures via computer-based and computer-assisted means.

Even more enormous changes are unfolding in the 1980s. The revolution in hardware has made it possible to compute almost anywhere, anytime and inexpensively; and the software revolution is about to compliment users in ways only imagined in the 1960s.

Dur_ _ the mid-to-late 1970s the DARPA/CTO-conceived Demonstration and Development Facility (DDF) concept was a reflection of the enormous changes which occurred during the period. Succinctly, the DDF was minicomputer oriented and served its community well as DARPA/CTO-supported contractors developed, tested, demonstrated, and transferred a whole host of minicomputer-based decision, forecasting, training, and information management systems. Clearly, the 1980s will see a major shift away from minicomputer-based systems to those which are portable, personal, and, consequently, distributed.

One of the major changes, therefore, was to not only include but emphasize the user: to have the individual interact more with the computing equipment; and also to permit several individuals to interact easily with one another. By creating a more symbiotic relationship between individuals and machines, and by permitting communication among individuals through the machines, the way was cleared for permitting the transfer or exchange of electronic data and text and human ideas and decisions. This symbiotic relationship was the hallmark of the new era in computing and what it truly introduced was an enhancement of human intellect, communication and, therefore, productivity. The stages in the evolution of this symobiotic relationship, as designed and built by CSM, are discussed next.

4.0 VIDEO TELECONFERENCING

Like all new research endeavors, the final product is the culmination of the successful completion of the different stages of each of the components. CSM was tasked to perform myriad smaller projects relating to the state-of-the-art computer software design, hardware engineering and video technology. These are the components that will eventually lead to the product of video teleconferencing. Different aspects of each of these components will be discussed in turn.

4.1 VIDEOLAB

The earlier evaluation of the new videodiscs, another evaluation of optical videodiscs (including the Capacitance Electronic Disc, the Video High Density System and the Transmissive Optical Disc) combined with the realization that briefings and other information could be distributed more widely and with less cost using video technology. These various crosscurrents, in conjunction with the traditional reliance on audiovisual materials, bought into being a Government Owned, Company Operated (GOCO) video production system. The idea was that by using colorful, edited, moving pictures, project managers would have at their disposal a concise medium to explain accurately products and concepts which once required volumns of textual description.

The Videolab provided creative services such as video scriptwriting, electronic recording, switching/mixing, and tape editing. Multi-media display and duplication services included videocassettes (1/2", 3/4", and 1") videodiscs, slides, overhead transparencies, Poloroid hardcopy, motion pictures, CRT's and large-screen video. The Videolab gave engineering assistance on computer/video signal interface. It also offered a library service for distributing videotapes and it maintained an AV resource file of companies performing specialized audiovisual services.

The Videolab also promoted the idea of sending information to people, rather than bringing people to the information. This was done primarily through the videotape library, but the process engendered the idea that the information could and should be sent immediately, rather than with a delay of several days, weeks, or months. And of course, the experience with video images and signals was invaluable.

4.2 ELECTRONIC NOTEPAD

During this phase of the project, several tasks were undertaken simultaneously: Videolab was one; evaluation of Hand Held Computers (HHC) was another; and the design and implementation of an electronic notepad was another. Although the concept of simulating electronically paper and pencil was not new, the prototype demonstrated that through state-of-the-art technology, the concept could be inexpensively and commercially reproduced.

The prototype had several constraints that made it unique. The first was that the cost of the equipment must not exceed $1500. The next was that the list of components must be available commercially to anyone. Furthermore, it was decided that development would not be limited to a single pad but should be able to incorporate more than one unit. These should be flexible enough to stand-alone as well as to inter-communicate with the others. In the networking mode multiple pads would share a common work area. Thus, the current image could be reviewed and edited by all network users.

The system incorporated various factors of human engineering to ensure ease of operation by the end user. As a part of these operational requirements, the pad had a menu which supplied five color options with which to draw and four functions: page forward; page backword; erase; and clear the page. Integral to the system was developing a means of storing and retrieving previously made drawings and notes. This was accomplished by using a mini-floppy disk capable of storing 35 pages of information.

Given these system parameters, the project was developed in three phases. The first phase involved the development of a single stand-alone prototype. Next, results from Phase One would be utilized in developing a four station network. Finally, a networking scheme would be used to institute telephone communication capability between Telepads.

The final hardware configuration included:

- Apple II microprocesor w/48k with a disk operating system;
- Kurta Bitpad;

- Color TV Monitor;
- Asynchronous Serial Interface Card - 7710; and
- Racal-Vadic 2445P/S Modems.

The above list of hardware components represented efforts to minimize cost and maintain flexibility in compatible hardware acquisition and software control. Figure 1 displays a single station of the electronic notepad, or as it was to be called later, Telepad.

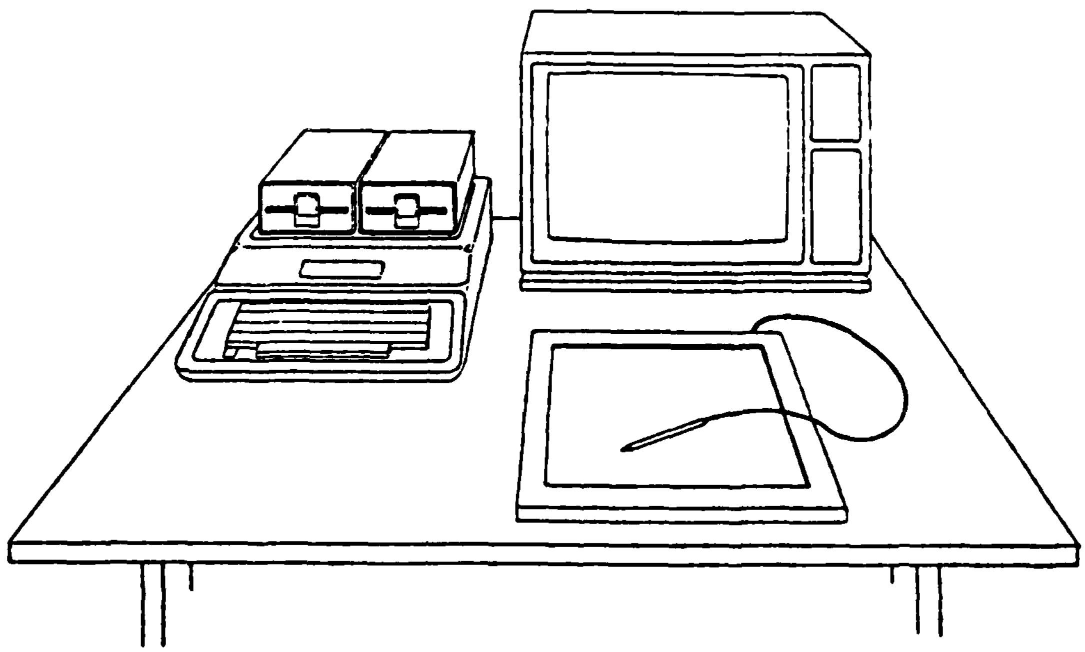

FIGURE 1

SINGLE STATION TELEPAD

Once the equipment was assembled, software was built in modules and integrated with a main driver routine. The modules included building a "user-friendly" main menu, which permitted the selection of a color with which to write and contained five functions to control movement between pages in addition to erasing and printing a hardcopy. Another module dealt with the problem of interfacing the Kurta Bitpad with the Apple computer. The Kurta Bitpad produced one type of information stream that was not acceptable to the Apple. And another important module dealt with compressing the information drawn on the screen so that it could be stored on a mini-floppy disk. Phase One of Telepad task was completed when all the modules worked together to get a single Telepad station functioning.

The second phase of the electronic notepad project involved the transformation of the single-station notepad into a network capable multi-pad system. Even though the single station telepad was prototyped to be compatible with the multi-station version, several difficulties had to be overcome. One was the concept of simultaneous drawing. This means that when one individual was drawing on a pad, the drawing would appear on all the other screens in the network. Another major difficulty was the limitations of the Apple computer's disk operating system. The disk system had to be able to save each page of information.

With these problems solved, four Telepads were placed in a ring configuration. The third phase of this project was the utilization of standard telephone lines and modems for transmitting the information around the ring of Telepads. Other difficulties were

encountered, but these were also overcome.

The initial research requirement of the project, which was to prototype an electronic version of the common notepad, was completed. The original cost parameters were slightly relaxed to approximately $4,000 to accommodate practicality and timeliness in completion of the project. Nevertheless, many available hardware products were ignored in order to finish within the already expanded cost limitations. An example was the low resolution of the screen which was a direct reflection of a limitation of the microprocessor architecture used in the development. However, by fully utilizing commercially available equipment and incorporating techniques such as data buffering and interrupt processing, the effort to reproduce the "shared" electronic notepad was successful.

While this has been an extremely brief review of this portion of the project, it has emphasized that inexpensive, commercially available telecommunications systems are possible. In addition, much of the advanced technical work (not even included in this review) help set the stage for the concluding component of this project. As that component (video-teleconferencing) is discussed, bits and pieces of the work up through the Telepad will reappear. The ideas and technical effort of simultaneous or shared drawing, networking by telephone lines and displaying video images of the users at each station, will all become even more refined.

4.3 TELECONFERENCING REQUIREMENTS

Building upon the results of Telepad, CSM was tasked to build a multi-node teleconferencing system. This system, like Telepad, was designed to operate using telephone lines (because of the low bandwidth) and was also supposed to be inexpensive (in relation to other teleconferencing systems). The teleconferencing system also represented, at CSM, the permanent interlocking of engineering and computing. Recall that this combination had its initiation several years ago during the Demonstration and Development Facility (DDF). One of the reasons computing and engineering became irreversibly interlocked during the teleconferencing project was because of the requirements of the project.

One of the major requirements established at the beginning of the teleconferencing project was that the conferencing had to work during times of national emergency or crisis. It was the Defense Department's desire to have a communications network that would be operating during these episodes of chaos and uncertainty. These requirements meant that all communications, audio and video, had to take place over extremely low bandwidths (like those needed by telephones). Engineering and computing tasks followed this requirement.

Another requirement was that the conferencing situation had to be as natural or normal in operation as a standard meeting. This meant all participants in the conference had to be represented individually and that their automated representations or surro-

gates had to function more or less like individuals. The idea behind this requirement was that in times of emergency, the teleconferencing should be as familiar as possible to the participants. The teleconference, in other words, would be an island of normalcy in a turbulent sea. Needless to say, engineering and computing efforts followed these guidelines.

Although the work followed these guidelines, emphasis was on the information sharing component of the teleconference. Two particular requirements determined the direction taken by both the engineering and computing efforts. Not unknown in the computing industry the two requirements, which are closely related, are that the information sharing must work in "real time" and "real motion".

"Real time", as is well known, is simply that the computing system must work at the same speed or in the same time span as the actions of its users. For example, if a user is editing text with a stylus on a touch-screen, the computing must operate in the same time as the stylus---crossing out a word, inserting another and circling another. Similar to this and extending the example, is that the motion of the stylus as it crosses out, inserts or circles must also be replicated by the computer as the speed stylus is moved by the user. Real time represents the precise speed of a graphics movement and real motion represents the precise accuracy of the movement. Finally, real motion must work in real time.

4.4 VIRTUAL SPACE

Virtual space technology was designed to follow one of the requirements stated previously; namely, that teleconferencing should simulate as closely as possible the structure and process of a real meeting. Each individual should be able to interact with others as they would in a meeting. When one person is talking, the others face that person. When another person speaks, attention is shifted to that speaker. But each listener, if they look at other listeners, will see that the others are also facing the speaker and maintaining "eye contact" with the speaker.

Those familiar with video-conferencing will immediately recognize the novelty to the virtual space approach. Most video conferencing systems do not permit this simulation of meetings. Indeed, most available video-conferencing systems show only groups of people to one another and miss altogether the nuances of intra-group interaction.

To achieve this effect of virtual space, rooms were designed for one person. Facing the desk in each room are four columns, each containing a TV monitor that displays a different individual, a camera and a loudspeaker. The first stage in virtual space was a four-station system with the video linked by ordinary coaxial cable, hardwired between each of the stations. The final system has five stations and is represented in Figure 2.

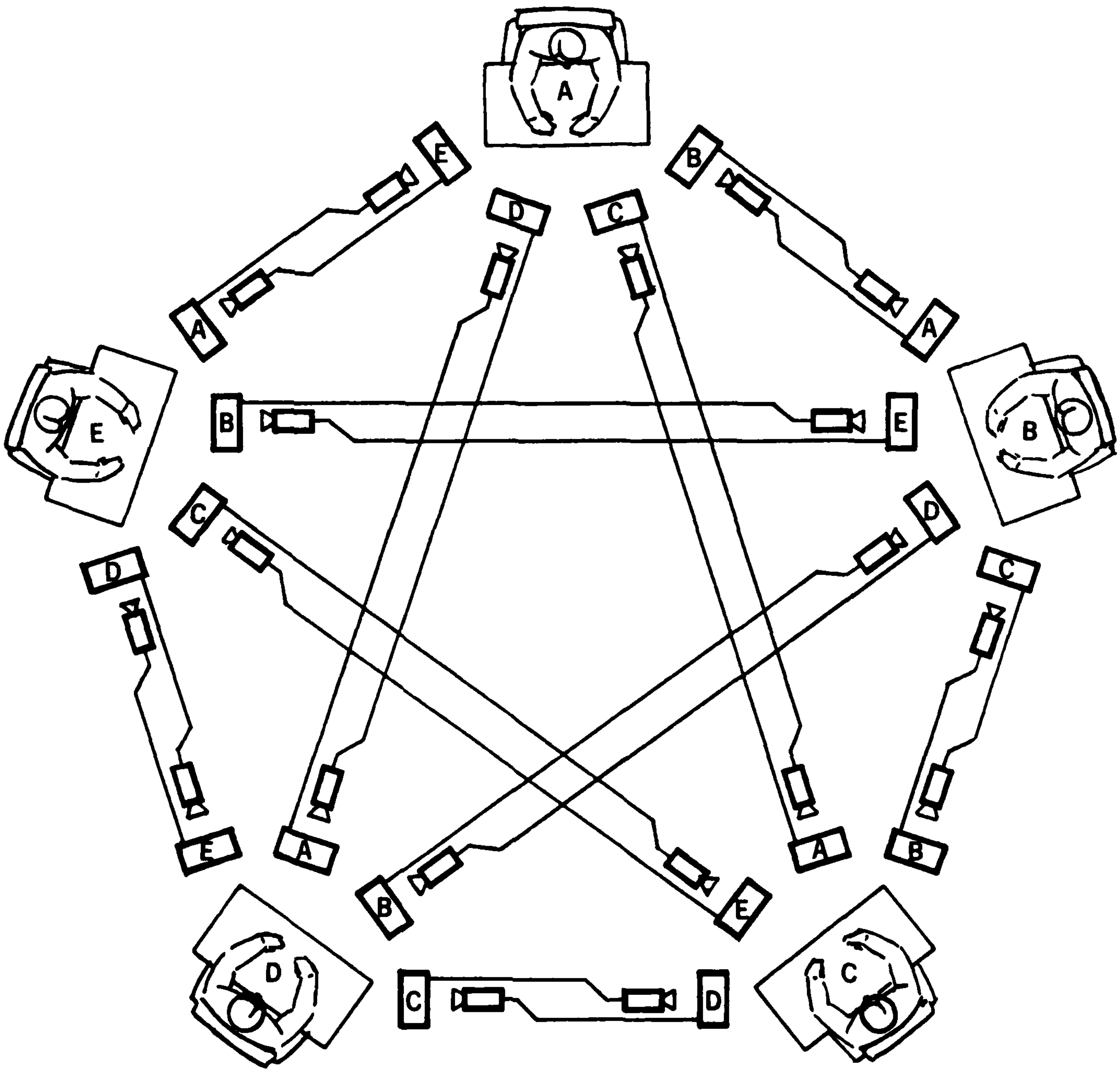

FIGURE 2

VIRTUAL SPACE
TELECONFERENCING
NETWORK

The physical design and appearance of the virtual space video-teleconferencing system differs substantially from conventional systems. Instead of placing all monitors (one for each station of the network) on a wall, the virtual space design isolates each monitor in its own column or cabinet. In conjunction with the camera and loudspeaker, the columns become the "conferee surrogate". Another advantage of this approach, in addition to the visual perspective just mentioned, is that the audio is localized to the individual columns. This permits each conferee to hear the voice of the individual who is talking, and associate the location of the audio with the location of the video.

A major task of the system was to present to each conferee the nonverbal communications of the others. Since most nonverbal communications are presented by facial expressions, cameras were mounted in a permanent position focusing on the face of the conferee. While this meant that camera operators were not required, the significance of this effort (to represent the facial expressions of the conferees), was the transmission of the facial image over a very small bandwidth: 19.2 kilobits per second or about 1/4700th of the full bandwidth.

To compress the information content of the image to such a small (and incidentally a much, much lower cost) bandwidth required the use of one of the new codecs (coder-decoders). The codecs in the system were built by Compression Labs, Inc. and used two dimensional run-length encoding to reorganize the information in the signal.

The result of this information manipulation is an image that corresponds to a pencil "sketch" of the individual. The "sketch" also "lives" as long as the actions of the individual are not too sudden or dramatic. To capture the individuals' actions, the transmission rate of frames is approximately seven to ten frames a second. And the display quality is high; the image is stored digitally and refreshed at a rate of about 60 frames per second.

The audio portion of virtual space has two components. One component permits verbal communication from each individual to all other conferees. This "global" component consists of a shotgun mike placed in an unobtrusive position and the signals are transmitted over standard leased lines. The second component permits private conversation between any two of the conferees. This "local" component consists of an ordinary telephone and autodialer wired with a cutoff switch to the shotgun mike so that all "local" conversations are private. Obviously, this component permits private conversation that in a traditional conference setting would be confined to the disruptive practice of subdued secondary conversing.

After numerous demonstrations and constant evaluation, it is clear that the strength of the virtual space aspect of the teleconferencing project is its remarkably small bandwidth. Recall that the bandwidth is only 19.2 kilobits per second (kbps). This means that even when four simultaneous images are transmitted, the total required bandwidth is less than 150 kpbs per station. And this includes telephone quality audio that is also compressed to 16kbps. Because a small bandwidth means substantially less cost, the bandwidth alone makes this system very

appealing; but when the small bandwidth is combined with the audio and video components of virtual space---and all this is added to the capability of sharing data---this teleconferencing system becomes truly exciting.

4.5 SHARED DATA

Shared data, the second key element of the teleconferencing system, evolved through experimentation and experience. The original telegraphics system, Telepad, consisted of four Apple computers communicating with one another in a ring network. The system provided a menu of options, inclusing five "ink" color selections, selections of a common graphics database and utility functions such as "clear screen".

Telepad cost little, but was effective. It proved to be adequate only when the subject matter did not require a large volumn of information to be passed among the users, however. Five colors could be displayed on a 280 x 192 pixel display screen. While adequate to display very simple charts, graphs and text, the system was not able to display documents or video. Finally, the menu displayed to the user was displayed on the video monitor. While convenient, the menu, needless to say, occupied a portion of the limited display area.

After Telepad, an initial Shared Graphic Workspace (SGWS) designed for a full-bandwidth virtual space system was developed. Each node contained a black and white TV monitor, a black and white overhead camera, an optical video disc player and a com-

puter terminal. Data was shared in this technology by placing material under the camera. Conferees could point at items in the material or write on it and these efforts were displayed to all the conferees. But this early version did not have storage and retrieval capabilities, high resolution or a color capability. Nevertheless, this first SGWS was easy to use and indicated the potential of this particular distributed computer graphics system.

In a later stage of development, the SGWS five-node low-bandwidth teleconferencing system was re-designed as an all digital color system to be operated jointly by the conferee and an assistant. Staff support is common in conferences; not only did this continue to simulate a traditional conference, but the assistant was the person responsible for searching for data. Also, the SGWS configuration consisted of a RGB monitor with a touch-screen and a digitizing tablet. Other equipment in the configuration included a videodisc player, data source interfaces, video switches and amplifiers, a sync-generator, a frame buffer, a DEC PDP 11/23 computer and the codecs. Figure 3 displays the configuration.

This is the current SGWS configuration. While the basic design of the five-node low-bandwidth teleconferencing has been completed, certain corrections and adjustments have been made.

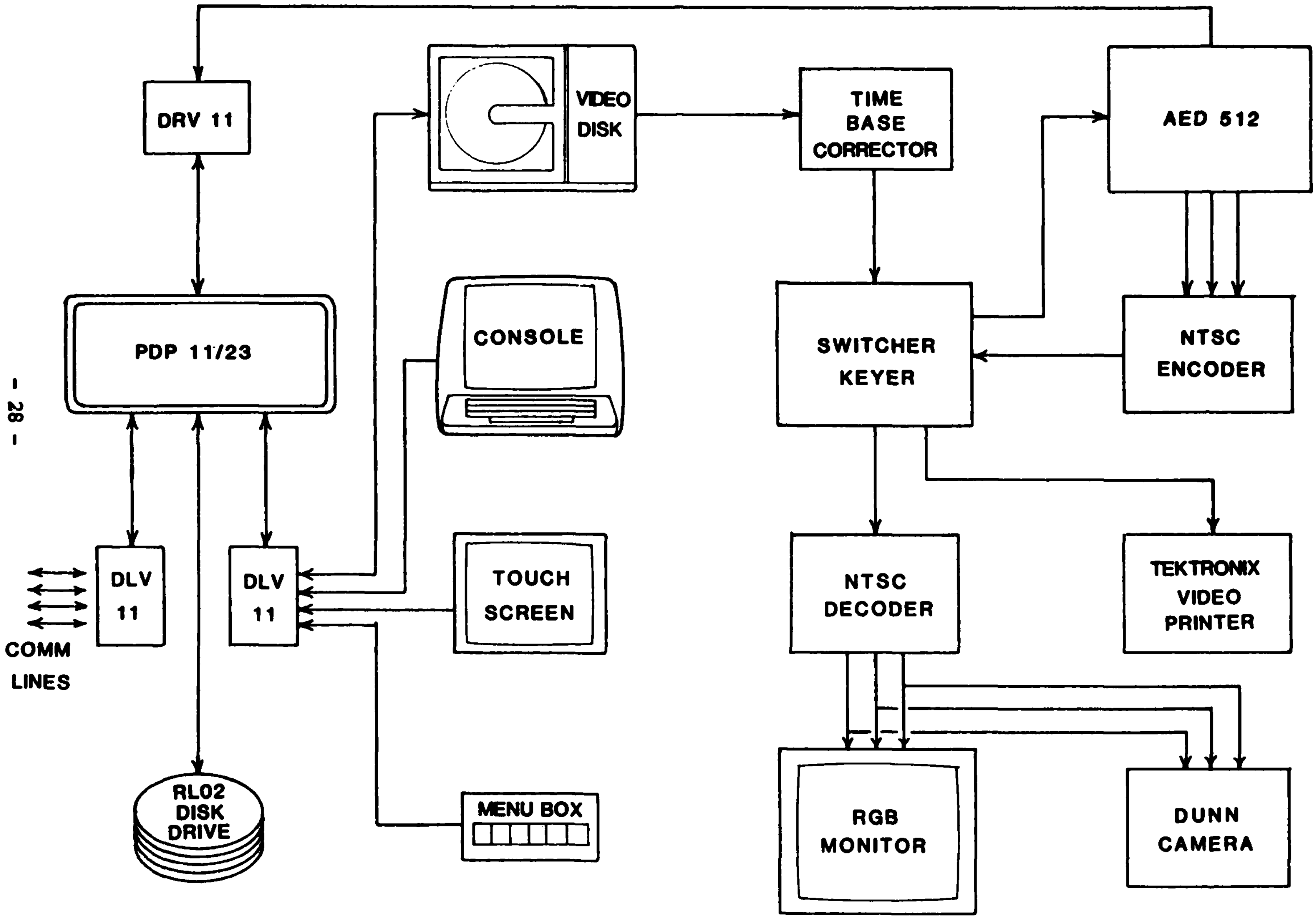

FIGURE 3

SYSTEM CONFIGURATION

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4.6 ADJUSTMENTS AND ACCOMPLISHMENTS

The work on the teleconferencing project in general and the SGWS component in particular was driven by engineering/hardware and computing/software considerations. Both of these considerations have to complement the other: the engineering developments would not work to their full potential without computing; and the computing accomplishments would be merely "interesting" without the engineering component.

A major adjustment during the current effort was changing the SGWS from an all digital system to a digital/analog system. This was done primarily to obtain high quality color images of maps. Maps, charts and other graphic information were stored on an optical videodisc. These different pieces of graphical information are "underlays" that could be brought up on a monitor with a touch-screen. The monitor with the touch-screen was mounted horizontally on a mobil pedestal. Also, a stylus was designed for "writing" on the touch-screen. This combination of monitor and stylus was designed to replicate pencil and paper. And finally menu boxes permitted the user to select the color of "ink" flowing from the stylus and choose other commands for information manipulation.

The brief summary touches on the major engineering accomplishments: menu boxes were built; touch-screen controllers were modified; and a mercury switch stylus was assembled. Most engineering work was dedicated to interfacing the input controls and the

output functions. For example, pushing the button for the color red on the menu box and then moving the stylus across the touch-screen are input protocols that had to be transformed into graphical output functions. The color of ink (red) and the stylus motion by one conferee at one station in the network is replicated on the monitors of all the other conferees on the network. And recall that this entire sequence (stylus on touch-screen, input controls and output function) works in real time and real motion.

The driving force behind the SGWS adjustments and the engineering accomplishments just mentioned was to encourage actual work in conference settings rather than emphasizing the process of a conference. The SGWS encourages work by permitting conferees to view information on the monitors and enables these participants to make corrections using their own designated color via the touch-screen and stylus.

Another capability of the SGWS is also on the menu box controls. In addition to the five color buttons are three buttons that control the writing function. At the bottom of the box are the buttons "next page" and "last page". These two buttons permit the conferee to view a page and then move on to the next page or review the previous page. In addition, the conferee can write on the page and the entire page (original information and conferee writing) will be saved. The "next page" button will automatically save the current page and then move to the next. Similarly, if the conferee stops using the SGWS on page three, but wants to review previous work at some time in the future, it is necessary only to press the "last page" button to retrieve pages

one and two. Those pages, with all their annotations, will be displayed on the monitor. To avoid confusion concerning which page is being viewed, a page number is constantly displayed for reference in the upper right hand corner of the monitor.

The best way to think of the SGWS is as a 20 page electronic reusable or easy-to-edit notebook. The notebook is easy to edit for the reasons just mentioned and it is reusable because of the "clear writing" button. Located at the top of the menu box, the clear writing button will erase all writing on the page. the page itself will remain intact---only the annotations of the conferees will be removed. The SGWS has a second erase capability but that will be discussed shortly.

It is important to emphasize that the pages which are saved or edited using the menu box are computer files. The SGWS also uses a videodisc player. This allows any video image to be displayed or annotated on the monitor, but any annotations will be saved in computer files. Currently the SGWS uses a videodisc containing 34,000 frames of recorded information. Each one of the frames can be displayed. It is also possible, using a computer terminal connected to the SGWS, to type in a name of a place and have a map of that area appear on the monitor. For example, a conferee could type in "El Salvador" and a map of El Salvador would appear on the monitor.

Computing and software accomplishments for the Shared Graphics Workspace (SGWS) is divided into the application of the software to each graphics node and the networking or linking together of the five nodes. Each of the nodes had to work: the input/output

functions; the save and store or next-page/last-page; and the capability of displaying various types of information from the computer files or videodisc. All of this had to function individually on each node. Then all the nodes had to work quickly and accurately on a low bandwidth, and therefore lower speed, network.

Two major achievements permit the fast and accurate operation of an individual graphics node. The first achievement, made possible by advances in hardware techniques, is the modification of the UNIX operating system drivers for Direct Memory Access (DMA). DMAs are hardware techniques for moving information to or from memory from or to the input/output (I/O) device. Generally, information transfer of this type requires regulation by the central processor. This regulation slows down the movement of information between memory and the I/O device. The DMA technique requires the central processor only to initiate and terminate the process. While information is moving from memory to the I/O device, and back again, the central processor is available for other tasks. At this time, the speed of the information transfer from memory to the I/O device is the maximum available. The significance of this complex effort is that the user waits only one second, rather than five, for a new display on the monitor. Given the current hardware constraints, this is as close to real-time as possible.

The second major achievement also pertains to speed and deals with the touch-screen controller mentioned earlier. The touch-screen controller is part of a graphics system. Many graphics systems are now obtaining real time capabilities through advances

in hardware techniques such as DMA interfaces, dual-ported memory and dedicated graphics processors. Despite these advances a major problem remained. The various input devices (touch-screens, bit pads and joysticks)do not send data to the central processor in formats acceptable to the graphics processor. This means that all the manipulations necessary for the correct graphical representations must be executed each time the coordinate pairs of the representation are changed. This process adds considerable time to the graphics processor, thus diminishing its real time attributes.

The achievement, therefore, is the modification of the software for the touch-screen to eliminate the need for the formatting manipulations by performing the formatting within the controller. The software modification does not repeat redundant coordinates and only requires one to four bytes to be sent to the central processor for each coordinate pair. Vastly improved speed is the result of this modification. Prior to the modification, plotting speed was 80 coordinates per second. After the modification, the plotting speed increased from 160 to 500 coordinates per second---or an improvement of 100 to 500 percent.

With the completion of the applications programming for each stand-alone node of the network, the task was then to tie in the entire network function. The The basic problem was taking the information coming in from any node of the network and then sending it out to all the other nodes. Much of the code for the network had been written during earlier phases of this project, so the job was simply making sure the network operated correctly. Several caveats are in order, however.

First is that the network is low-speed. While this appears initially as a disadvantage, the network is highly configurable and will work anywhere there are telephones. This means that the entire network can operate simply with modems and even have auto-dialing cababilities (dedicated lines are only a frill). Second, the prototype network had been tested using only five nodes, but it could still function with a total of eight nodes. And finally, the typical configuration is a local-area network or a network that is "hard wired" together. Advantages of the local-area network is that it by-passes modems with auto-dialers and can be used in the same building or in offices of close proximity. But this typical system is not as configurable as the wide area low-bandwidth network.

4.7 FINAL ENHANCEMENTS

Before discussing the final, or more correctly most recent, enhancements to the teleconferencing system, a few minor albeit interesting accomplishments are discussed. One is that it is possible to place information on the network from a word processor. Since many offices use word processors, being able to move information from the processor to the network is convenient and saves duplicating effort. Another is that electronic information stored on other networks, such as The Source or Dialog, may be loaded onto the network. Virtually any type of electronic information that can be accessed by telephone or easily transferred can be share by the users on the network.

Two other enhancements were placed on the current network. One is that all text was white on a black background. This was changed to black text on an amber background for readabiliy. The other was that when the videodisc was moving between pages, the monitors would flicker while waiting for the change. The enhancement of this was to place a blank "page" between the videodisc images, thus eliminating the flicker. Both of these enhancements were designed to make viewing much easier and more pleasant for the user.

One of the later enhancements increased the storage space on the re-usable notebook (the computing file) from 20 to 132 pages. The benefit of this enhancement is obvious: larger or several different documents can be placed in the system. Another enhancement designed to make the system more efficient is the automation of the back-up procedure of the information on the system. Automation of this important computing procedure further reduces the chance of losing valuable information. Further aiding the user is the implementation of menus for briefing preparations. Clearly, this helps the user's organization. Mentioned briefly in the previous section, another enhancement is the installation of a remote access modem to make connection to other networks (e.g., the Source or Dialog) easy and fast.

Two final enhancements are worthy of special attention. The first enhancement places information stored on a written page onto the network. The significance of this enhancement is far reaching. Written pages will not have to be re-entered in a word processor and then transferred to a node on the network. Instead, traditional (printed on paper) pages or reports will

simply be copied by a facsimile machine. The resulting copy, instead of being transmitted to another fax machine, is placed on the network. This enhancement aids the transition from traditional offices and conferencing to electronic paperless offices and conferencing.

The final, for the time being, enhancement is a voice store and forward capability. This enhancement is analagous to a tape cassette. The speaker can make a presentation for the network, store it, and then forward it to all the other conferees. The listening conferees are then able to receive the speaker's presentation at their leisure. This is another enhancement that personalizes communication among individuals who are scattered across the country or around the world and separated by time zones.

The main intent of this portion of the report has been to outline the technical achievements of, primarily, the Shared Graphics Workspace (SGWS). Recall that the major requirement of the SGWS was that it resemble as closely as possible traditional work tools such as pen and paper. This requirement meant that all engineering and computing capabilities had to work in real time and real motion. Given existing hardware and software constraints, the engineering and computing efforts met the goal of working in real time and motion. In this sense, therefore, the technological work on the SGWS must be termed successful. But the success of this work extends beyond the technological achievement.

The real success of these technological achievements is the close adherence to the true purpose of a conference. Information is shared, work is done, and decisions can be made---just as in a traditional conference. The technology permits face-to-face contact, verbal and non-verbal communications and the presentation of text and graphics. The structure and process of a conference are represented by the concept of virtual space, and the function of a conference (to exchange and correct information) is made possible by the Shared Graphics Workspace.

It is no small accomplishment to replicate via state-of-the-art technology human interaction and behavior. It is an even greater accomplishment to use technology to promote human interaction. The real value of this technology, therefore, is its capability for promoting the work necessary for the completion of group tasks and decisions.

5.0 CONCLUSION

The main idea behind these efforts was to bring contemporary technology to an age old problem---how to sort through very quickly a large amount of information, make a decision based on that information and then express the decision to others. The national security/defense context of this problem was an international crisis or any other time that was rich with uncertainty and chaos and impoverished with accurate information and clear channels of communication.

While the basic problem was old, the technology was new and constantly changing. The solution to the problem, even in this largely experimental environment, was tied to the technology of the times. The Demonstration and Development Facility, therefore, was hailed as a model for attempting to solve the problem of making decisions during times of uncertainty. Data and software were brought together and demonstrated to the Defense and Intelligence communities. But no sooner was the DDF established than it was quickly outdated by the rapid advances in the information industry.

Personal utilization and communication among the personalized computers became the hallmark of the information industry. Computers were smaller and smaller and were designed to be entirely operated by a single individual, not an entire staff. But people do not live or work in isolation; they do communicate with others, and the information industry moved to aid communication.

The Defense Department immediately recognized the value of these developments and sought to move into these aspects of the information industry, but with the research and development tailored to their requirements of command and control during times of tension or emergency.

More than anything else, this project (especially its final product) harnessed modern technology and fit it to the problem at hand. The project avoided much of the exotic, and expensive, video and computing developments that are available and still developed a very innovative and unique system. It is the uniqueness and simplicity of idea that makes the final product of this project so compelling: compelling because after years of experimentation and research, a video/computing system was designed, built and tested so it could actually be used by people to do their work.

6.0 REFERENCES

This reference list is designed to be a quick guide to the technical reports produced during the period of this contract. Since all the reports were produced by Computer Systems Management personnel, an abbreviated reference listing is followed. Only report number and title are offered. While this may not meet normal standards of report preparation, it is done so the reader will have a reference list that will encourage seeing, using and experiencing the technology. The references are listed in chronological order.

Quarterly Technical Report 80-01. The Development, Demonstration, and Documentation of Advanced Command and Control (C2) Computer-Based Systems.

Quarterly Technical Report 80-02. The Design and Transfer of Advanced Command and Control (C2) Computer Based-Systems.

Quarterly Technical Report 80-04. The Design and Development (D2) of Generic Microcomputer-Based Command and Control (C2) Decision and Forecasting Systems.

Final Technical Report 80-05. The Design, Development, Demonstration and Transfer of Advanced Command and Control (C2) Computer-Based Systems.

Quarterly Technical Report 81-01. Defense Microcomputing in the 1980s: Problems and Research Priorities.

Quarterly Technical Report 81-02. Microcomputer Software Engineering, Documentation and Evaluation.

Quarterly Technical Report 81-03. Video-Based Systems Research, Analysis, and Applications Opportunities.

Final Technical Report 81-04. The Design, Development, Demonstration, Documentation and Transfer of Advanced Command and Control (C2) Computer-Based Systems.

Semi-Annual Technical Report 82-01. The Design, Development and Application of Advanced Video and Microcomputer-Based Command and Control (C2) Systems.

Semi-Annual Technical Report 82-02. The Development and Application of Advanced Video and Microcomputer-Based Command and Control (C2) Systems.

Semi-Annual Technical Report 83-01. The Development and Application of an Advanced Computer-Based Shared-Graphic Workstation for Video Teleconferencing.